Bioenergy

Los Alamos developing next-generation of biofuels from renewable resources

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Los Alamos scientists used genetic engineering to develop magnetic algae, thus making it much easier to harvest for biofuel production. Harvesting algae accounts for approximately 15–20 percent of the total cost of biofuel production—magnetic algae can reduce such costs by more than 90%.
Overview of Research and Highlights

The next-generation of biofuels are being developed at Los Alamos. Made from renewable resources, biofuels could yield reduced carbon dioxide emissions.

Los Alamos scientists are

- working to bring cellulosic ethanol (made from the inedible parts of plants, instead of corn) and algae-based fuels to the marketplace in ways that make them economically competitive with fossil fuels and prevent a strain on valuable food crops.
- investigating the use of genetically engineered microorganisms to produce fuel directly from carbon dioxide, as well as creating commodity chemicals—like plastics and food additives—that traditionally come from fossil fuels.

Scientists at Los Alamos are working to create competitive, sustainable forms of bioenergy. Approaches include genetically modifying algae for cost-effective biofuel production to one day using nonedible biomass materials like corn leaves or switchgrass to produce forms of usable energy. Projects include

- improving the efficiency of plant photosynthesis
- advancing algae production and harvesting
- gaining a better understanding of the structure and biochemical and thermochemical conversion of cellulose for use in fuel production

Algae Science and Algal Biofuels

- Developed the Ultrasonic Algal Biofuel Harvester, which provides a low-cost, environmentally benign, and energy-efficient source of algal lipids for use in biofuels. This technology won an R&D 100 Award in 2010. In 2012, the National Alliance for Advanced Biofuels and Bioproducts selected this technology for Phase

II development, and in collaboration with Solix BioSystems, a scaled-up system is currently being field tested for use in fuel production
- Used genetic engineering to develop magnetic algae, thus making it much easier to harvest for biofuel production. Harvesting algae accounts for approximately 15–20 percent of the total cost of biofuel production—magnetic algae can reduce such costs by more than 90%.
- Working to produce a high-performance version of an enzyme known as carbonic anhydrase that could (1) reduce carbon emissions from coal- and gas-fired power plants and (2) play a valuable role in increasing algae growth for the production of algae-based biofuels.
- Sequenced 8 complete algae genomes and 11 transcriptomes, as well as created an annotation pipeline, thus providing the first available comprehensive sequences of algae that will help scientists identify species and characteristics best suited for biofuels production.
- Using sequence data, identified key metabolic pathways of lipid biosynthesis to enhance biofuels production by addressing significant alterations in carbon partitioning from growth to lipid accumulation caused by nitrogen depletion.

Cellulosic Biofuels

- Using mechanistic kinetic models, agent based (rule-based) modeling, statistical mechanical and coarse-grained models, all-atom molecular dynamics simulations and quantum chemical calculations to tackle the challenge of biochemical and thermochemical conversion of biomass
- Quantified—for the first time—the stacking interactions in cellulose fibril—this continues to be one of the top-ten accessed articles for The Journal of Physical Chemistry A since its publication more than an year ago.
- Developed vanadium catalysts that can break down nonfood biomass known as lignocellulose, an attractive alternative as a feedstock used to produce renewable chemicals and fuels.
- Created pipeline for protein evolution of cellulases (enzymes that degrade cellulose) and thermostable cellulases that are optimized for industrial environments.
- In collaboration with the Great Lakes Bioenergy Research Center (GLBRC), made important progress toward the optimization of ammonia-based pretreatment strategies for efficient degradation of cellulose by cocktails of enzymes.

Plant Growth Science

- Applying metagenomics to learn how to adapt microbial fuel production to widespread application.
- Optimized photosynthetic antennae size in algae and plants to improve biomass yield by 30%.
- Engineered improved carbon fixation in algae to enhance photosynthetic rates by 60%.
- Engineered improved respiratory carbon metabolism in algae to increase oil yield two-fold.
- Used metabolomics to enhance plant growth.

Food Security

- Enhanced the levels of iron and protein in cassava to meet the minimum daily requirement in a typical sized meal
- Extended the shelf life of cassava from 2 days to three weeks after harvest to increase food security
- Reduced the levels of toxic cyanogenic glycosides in processed foods.

Resources and Sustainability

- Demonstrated—both in the field and in the laboratory—that produced water (extracted with oil or gas) is a viable medium for marine algae such as Nannochloropsis, and for brackish-adapted algae such as Scenedesmus. The water also has been shown to contain valuable nutrients for the algae, including high levels of bicarbonate, potassium, and iron.
- Collaborated with SIMTECHE to develop a cost-effective carbon dioxide capture process that will enable carbon capture that could one day enhance the availability of carbon dioxide to drive photosynthesis for algae production. This technology won an R&D 100 Award in 2009.

Fuel Conversion

- New biomass conversion technologies have been discovered to produce hydrocarbons and platform chemicals using completely novel molecular pathways and catalytic approaches. The patent pending compounds and methods could potentially show superior economics as compared to those currently industrially used.

Capabilities

Bioinformatics and Analytics	Patrick Chain
Biomass and Diversity	David Fox
Biophysical Chemistry	Ryszard Michalczyk
Computational Modeling	Ben McMahon
Genome Technologies	Tracy Erkkila
Molecular Recognition and Design	Andrew Bradbury
Protein engineering	Geoff Waldo
Structural Biology	Tom Terwilliger

LANL Facilities and Resources

- LANL-New Mexico Consortium Photobioreactors: Housed at the New Mexico Consortium (NMC) and shared between LANL and NMC, the ePBR Matrix consists of 33 Phenometrics ePBRs that simulate a microalgal biofuel pond production environment with control of depth, light, turbidity, pH, temperature, and gas delivery. This system is available to users in the scientific community.
- Protein Crystallography Station: This facility uses neutron diffraction techniques to perform groundbreaking work in understanding enzyme structure and function, as well as elucidating the structure of cellulose (the building blocks of biomass). The enzymes studied here can be used in a multitude of ways, including the reduction of carbon emission in power plants and enhancing the production of algae-based biofuels.

- National Flow Cytometry Resource: For more than 30 years the Laboratory has been a leader in the development and use of flow cytometry. Flow cytometry is useful for the sorting and analysis of algae cells for bioenergy, and the 2008 R&D 100 Award-winning acoustic flow cytometer inspired development of the Ultrasonic Biofuels Harvester, a 2010 R&D 100-award winner.
- National Stable Isotope Resource: This facility fosters the creation of new, efficient routes to synthesize stable isotopically-labeled compounds. As such, the facility plays a valuable role in metabolomics for plant growth and biofuel production.
- Joint Genome Institute (JGI): Los Alamos was one of the founding partners in the DOE-JGI over 10 years ago. Los Alamos scientists continue to contribute scientifically to in high-throughput genome finishing and analysis in support of DOE missions in energy, bioremediation, and carbon sequestration. Work includes developing assembly algorithms for sequence improvement of microbial genomes, and advanced bioinformatics analysis of metagenomic communities.
- Los Alamos Genome Center: The Genome Center houses all of the newest sequencing technologies primarily focusing on sequencing critical pathogens and near neighbors as well as microorganisms useful to bioenergy research. In addition to initial sequencing, the Center engages in computational finishing and bioinformatics characterization, database and web services for genome comparisons, metagenome sequencing and analysis for pathogen discovery and biosurveillance.
- High-Throughput Gene Cloning and Protein Production Facility: This facility serves the Tuberculosis Structural Genomics Consortium, the Integrated Center for Structure and Function Innovation, and an NIH project to select antibodies against every human protein.
- Protein Structure Determination: Multiple facilities at LANL provide capabilities in NMR, and X-ray and neutron diffraction techniques to perform groundbreaking work in new drug-design methods through advanced understanding of protein structures and their functions.

Partners

- New Mexico Consortium's Biology Research Facility: In 2012, Los Alamos began construction of the New Mexico Consortium’s biology research facility. Scientists in this 24,000-square-foot research facility and greenhouse will focus on biofuel research, particularly fuels derived from certain plants and algae.
- National Alliance for Advanced Biofuels and Bioproducts (NAABB): LANL is a leader in the NAABB, a consortium of National labs, Academic Institutions and Industry working to produce new technologies that can be implemented by our commercial partners and others developing the algal biofuel industry.
- National Advanced Biofuels Consortium (NABC): LANL is a partner in the NABC, a consortium developing cost-effective processes to produce biofuels that are compatible with today's transportation infrastructure.
- Center for Advanced Biofuels (CABS): LANL is a partner in CABS, a DOE Energy Frontiers Research Center focusing on improving the thermodynamics and kinetics of lipid-based biofuel production.
- Photosynthetic Antennae Research Center (PARC): LANL is a partner in PARC, a DOE Energy Frontiers Research Center focusing on improving the efficiency of light utilization by light harvesting antennae complexes.

- Center for Enhanced Camelina Oil (CECO): LANL is a partner in CECO, a DOE-ARPOA-E program focusing on improving the photosynthetic and oil production efficiency of camelina for use as a dedicated biofuels crop in the US.

Sponsors, Funding Sources, or Agencies

- Department of Energy, Science-Office of Biological and Environmental Research
- Department of Energy, Energy Efficiency and Renewable Energy-Office of Biomass Programs
- U.S. Department of Agriculture
- National Science Foundation

Awards

- 2010 R&D 100 Award for Ultrasonic Biofuel Harvester
- 2009 R&D 100 Award for SIMTECHE